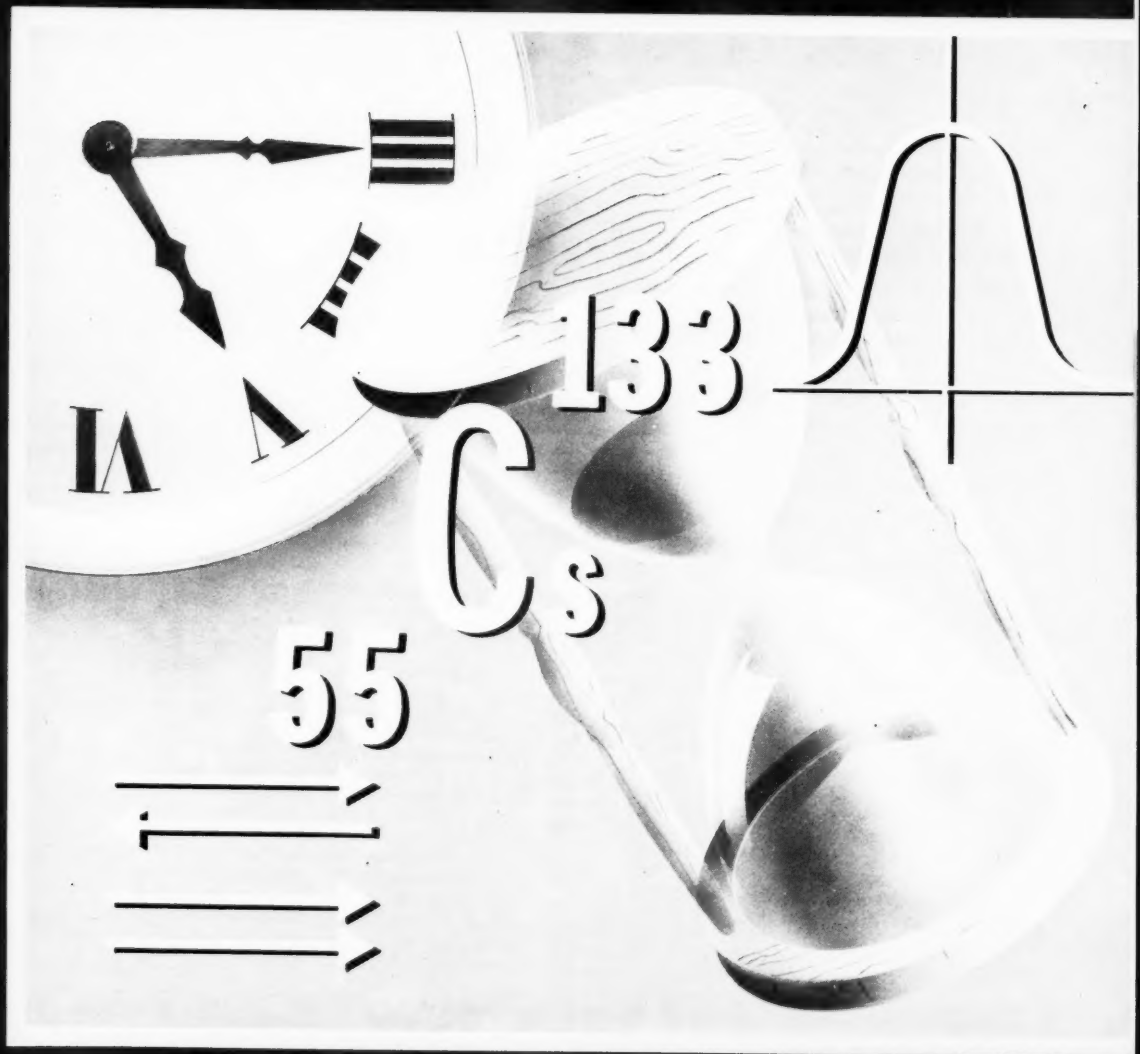
RAYTHEON

ELECTRONIC PROGRESS



In this issue:

ELECTRONIC PROGRESS

VOLUME 1 JANUARY - FEBRUARY 1957 NUMBER 4

RAYTHEON

ELECTRONIC PROGRESS

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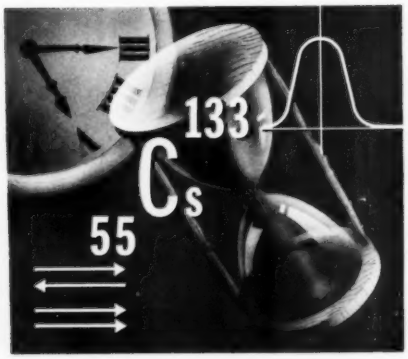

The precise measurement of time intervals has become an important factor in our present day technology. Modern devices capable of performing this measurement with the required accuracy and stability are becoming more generally available. These devices employ resonant elements such as the cesium atomic beam, the ammonia molecular oscillator, the microwave absorption cell and the quartz crystal.

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Calendar

Northeastern University Off-Campus Courses

Course	*Place*	*Time and Date*
Transistor Circuit Engineering	Training Center Waltham	Mon., 6-8 P.M.
Theoretical Physics	Training Center	Tues., 6-8 P.M.
Physics of Semiconductors	California Street	Wed., 6-8 P.M.
Transients in Linear Systems	Training Center	Wed., 6-8 P.M.
Principles of Microwave Tubes	Training Center	Thurs., 6-8 P.M.
Radar Engineering	Wayland Cafeteria	Thurs., 6-8 P.M.
Advanced Mathematics Sec. I	Training Center	Fri., 6-8 P.M.
Advanced Mathematics Sec. II	Research Building	Fri., 6-8 P.M.

For information call Robert C. Story, Extension 495, Waltham

Other Seminars and Courses

Space Charge Seminar	Research	As required
Ceramics Seminar	Research	Last Tues. of mo.
Welding Engineering	S. Wal. Jr. H.S.	Each Tues. at 6:00 P.M.
"Solid State Masers" — Prof. N. Bloembergen, Applied Physics Dept., Harvard University		Wed., Jan. 23*
"The Thermonuclear Program" — Prof. M. Clark, Nuclear Engineering Dept., M.I.T.		Wed., Feb. 6*
"Elementary Principles of Information Theory" — J. Mullen, Research Div., Raytheon		Wed., Feb. 20*
"CW Radar" — T. Gross, Missile Systems Div., Raytheon		Wed., Mar. 27*
"Microwave Ferrite Devices" — H. Scharfman, Missile Systems Div., Raytheon		Wed., Mar. 6*

Place and Time — Wayland Cafeteria 5:20 p.m.

Technical Committee Meetings

Plastics	Varies	2nd Tues. or Thurs. of the month
Ferrite	Varies	1st Wed. of the month at 3:00 P.M.
Transistor Circuit	Research	As required
Welding	Varies	1st Thurs. of the month at 3:00 P.M.
Magnetic Amplifier	Wayland Laboratory	As required
Engineering and Scientific Co-ordinating Committee for Digital Computers	Research	As required

Technical and engineering personnel who desire further information concerning the above calendar should contact Mr. James Sterling, Research Division, Extension 2187.

Backward Wave Oscillators

R. McC. UNGER

Microwave and Power Tube Operations

PERFORMANCE of Backward Wave Oscillators was disclosed simultaneously in 1952 by R. Kompfner of Bell Labs. and B. Epsztein of CSF.* The nature of this new microwave signal source is such that electronic tuning (i.e. frequency change occasioned by change in potential of an electrode) over complete waveguide bands could be accomplished. The simplicity and sweeping speed of such a device claimed immediate and widespread interest. Equipment designers, for example, could foresee elimination of the intricate and slow tuning mechanical systems presently required in broad band signal sources.

Raytheon's early entrance into the field of BWO development was aided by our affiliation with CSF. Two types of backward wave oscillators were known. One, called the "M" type, uses crossed magnetic and electric fields analogous to those of the magnetron. This article treats only of the second or "O" type in which the magnetic field is used solely for focusing the electron beam. Design parameters, backed by experimental results, as well as prototype tubes were made available to the Beam Tube Research and Development department within the Power Tube Operation. This engineering group had been devoted largely to the design of reflex klystrons where the oscillation mechanism involves cavity resonance sustained by electron interaction across a single gap. We now found ourselves concerned with essentially continuous interaction of an electron beam with a wave traveling along a non-resonant structure — hence the name Traveling Wave Tube. The Backward Wave Oscillator, both historically and physically, is but an outgrowth of this general type.

For the simplest form of TWT we would merely shoot an electron beam along a transmission line. Action of the electromagnetic wave on the beam would produce electron bunching and the bunches would, in turn, interact with the field. By proper choice of the phase of this latter interaction, beam energy can be transferred to the wave. This bunching and re-enforcement action can be made essentially continuous as long as the proper phase relationships are maintained, so that an appreciable portion of the beam energy can be utilized in amplification of the r.f. wave.

In the example stated of the straight transmission line, beam velocity must be that of the wave if the desired phase relationship is to be maintained — known as the "condition of synchronism." The wave travels, we know, with the velocity of light and is independent of frequency. Thus a single beam velocity yields a synchronous condition for amplification over a broad band of frequencies. Such a structure would therefore be called "non-dispersive." The required beam velocity, c, is not, of course, realizable. If, however, we were to distort the wave transmission structure into a helical shape we would reduce the forward (or axial) wave velocity by the ration of helix circumference to pitch, and synchronous axial velocities could be achieved at practical voltage levels. This device is non-dispersive in its fundamental forward mode; i.e. phase and group velocity are in the same direction. This property finds extensive use in traveling wave tube amplifiers.

Still another method of distorting the transmission line, more suited to the BWO, is to fold it back and forth on itself. If we visualize a parallel plate line bent back and forth, the zig-zag path to which the wave is constrained serves this same purpose of retarding axial wave velocity. The structure would have the appearance of interlaced fingers. See Figure 1. The use of such a structure, called an inter-

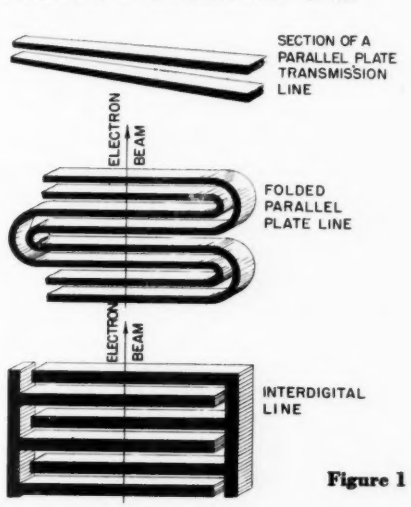


Figure 1

* Compagnie Générale de Télégraphie Sans Fil

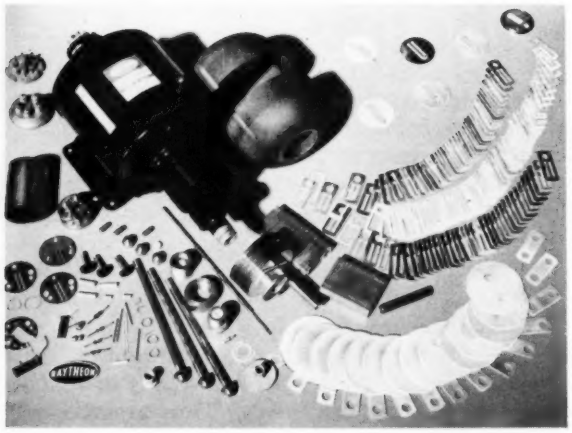


Figure 2

digital line, was emphasized by CSF because it then appeared, as it does today, to have distinct advantages over the helical slow wave structure more generally utilized in this country. Since the wave periodically reverses direction, it is not surprising that the fundamental mode has a negative group velocity (therefore known as "backward wave"). Further, since the physical dimensions of the line are such that these reversals are spaced appreciable portions of a wavelength apart, we might expect the axial phase velocity of the wave to be dependent on wavelength of operation. (Synchronism between phase and beam velocities provides the mechanism for amplification.) Such is indeed the case; a linear approximation of the dispersive characteristic of the structure can be derived:

$$c/v_p = \frac{\lambda - 2\,(l + p)}{2p}$$

where:

- c = velocity of light
- v_p = phase velocity
- λ = wavelength
- l = finger length
- p = pitch

This interdigital line structure we see provides us with a voltage tunable oscillator which features: 1) amplification of a wave whose frequency is selected by choice of the synchronism beam velocity; and 2) feedback through the negative group velocity feature. Another salient feature of the interdigital line structure results from the fact that problems of beam coupling are reduced over those of helix construction. It is in mechanical design, however, that the interdigital line really shows to advantage.

Early in 1954, work began on an S-band backward wave local oscillator with electrical dimensions made available through a CSF prototype tube. The Raytheon version (QK518) was to be restricted only in that it had to be capable of serving as a direct replacement for the prototype. Further, full advantage had to be taken of the inherent ruggedness of an interdigital line structure. The tube design also had to be suited to the needs of high scale production.

Figure 2 shows the parts and their assembly used in fabrication of the finished design tube. The most significant feature is found in use of the lamination method. First developed by Raytheon early in World War II, it has proven eminently successful in magnetron production. This technique not only gives us a proven production method, but carries with it all those advantages which occur from the use of punched parts. Thus we automatically have pieces made to the close tolerance and uniformity required of tubes using a periodic slow wave structure.

Each lamination is shaped so that its dimensions correspond to a cross-section of the structure to be utilized. Thickness of each part is chosen to coincide with dimensional changes in cross-section occasioned by different axial positions within the unit. The interdigital line is ideally suited to this technique, requiring but three basic lamination types. One part would have a solid rim with a finger protruding into the central hole. In the second piece, the finger is made to extend from the opposite side. A third part, comprising only the rim, serves to provide the desired separation between fingers. Stack-

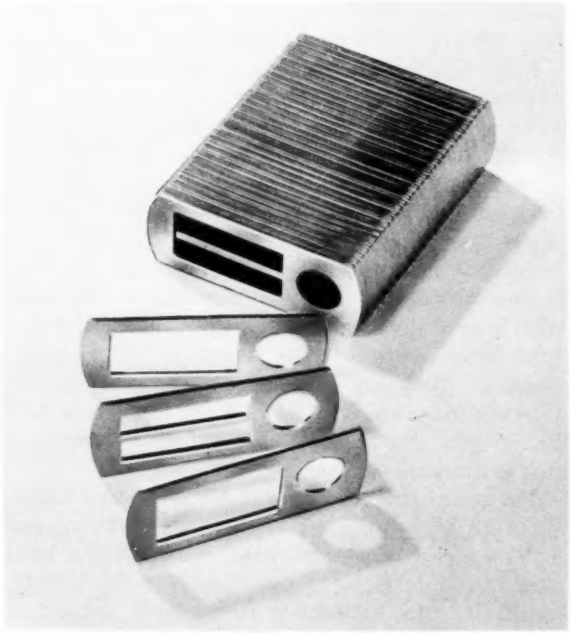


Figure 3

ing of alternate finger and spacer laminations results in the desired interlaced finger (inter-digital) slow wave structure (see figure 3). The metal envelope formed by the rims, coupled with ceramic seals, yields a ruggedized structure not found in other BWO's.

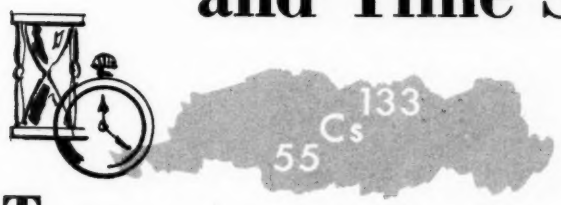
The slow wave structure is relatively massive and provides a good thermal path to the envelope so that beam interception introduces no mechanical difficulties. We are thus relieved of the necessity for complicated gun design and accurate magnetic field alignment. The volume adjacent to each side of the fingers is merely flooded by the beam.

For applications where rapid and wide band sweeping is desired, the BWO is far and away the best tube available today. Rate of tuning is found to be limited only by transit time effects within the tube, so that the entire frequency band can be swept at rates of the order of megacycles per second. Further, the control grid provides amplitude and pulse modulation capabilities comparable with the best performance of other types of microwave oscillators.

Generally speaking, we pay for BWO advantages only in increased tube weight and stability of power supplies. The added weight derives mainly from the need for a magnet to maintain beam focus. (It is not inconceivable that improvements in the art will some day obviate this requirement.) Since, as we have seen, frequency of operation is determined by delay line voltage, it necessarily follows that frequency stability depends upon the degree of stability of the associated power supply.

The design described in the previous section has been tested and proved with production of about 400 QK518 tubes. It is the mechanical prototype for higher frequency range tubes now in the development stage. Our present situation is such that we can supply BWO's anywhere within the 1000 to 16,000 megacycle range, each tube tuning the better part of an octave. Prototype tubes serve to fulfill small quantity (experimental) orders. As demand increases, mass produced types made by Raytheon will be substituted. This program is aimed at maintaining Raytheon's favorable position in the microwave local oscillator field as and when emphasis shifts from the reflex klystron to the Backward Wave Oscillator.

Accurate and Stable Frequency and Time Standards



S. AISENBERG
Research Division

THERE is a need for extremely stable time and frequency standards, both for laboratory measurements and for navigational purposes. The heart of such devices is a resonant unit whose absorption and release of energy at a given frequency is extremely dependent upon the deviation from a stable characteristic frequency. The interaction between an oscillator and the resonant element is usually monitored by a feedback loop which operates to change the oscillator frequency so that there is a constant interaction, and thus makes the oscillator frequency differ from the resonant frequency by a small but constant amount. The closeness of the oscillator frequency to the resonant frequency is determined by the sharpness of the response of the resonant circuit (the Q of resonant element) and the ability of the interacting circuit to detect small changes of resonant circuit response resulting from a slight change of oscillator frequency. At the present time, four types of resonant elements that are capable of yielding quite stable frequency standards are — the quartz crystal, the absorption cell, the cesium atomic beam, and the ammonia molecular oscillator.

One very satisfactory way of using the quartz crystal as a frequency standard is to use it as one arm of a resistance bridge circuit driven by an oscillator with a feedback loop designed to change the oscillator frequency until the phase shift in the bridge is almost zero. There are two major causes of crystal oscillator instability. One is slight temperature changes acting through the dimensional temperature coefficient of the crystal, and the other is the ageing of the crystal, both of which change the dimensions of the crystal and therefore the mechanical vibrational frequency of the crystal. The temperature coefficient of quartz is about 5×10^{-6}/°C, but by using special crystal cuts (such as the GT cut) the temperature coefficient can be re-

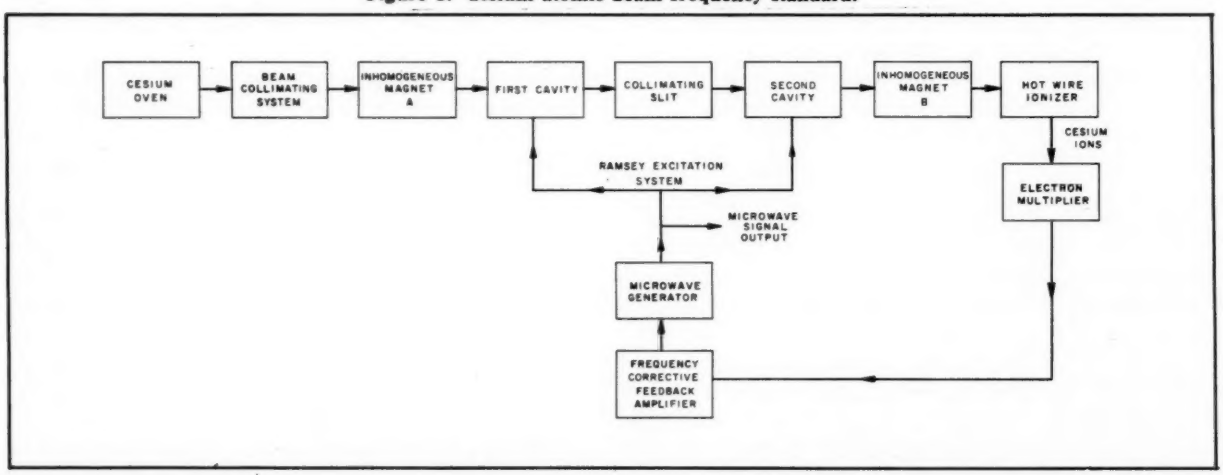
duced to about 2×10^{-7}/°C. A well regulated temperature oven will considerably reduce the temperature coefficient effect. The ageing of the crystal corresponds to the release of internal stresses, loss of loose surface layers of quartz, and change of surface layers on the quartz. A change of approximately 1/50 of a surface monolayer will result in a frequency change of 10^{-9}. These effects can be reduced by using etched, baked, well outgassed quartz crystals mounted in vacuum. Quartz crystals have a Q of about 0.3×10^6, although some have been reported with a Q as high as 12×10^6. Crystal oscillators have been reported with a stability of about 10^{-10} per day and 3×10^{-9} per month.

The microwave absorption cell method uses the absorption by gas atoms or molecules of microwave power of the right frequency. In this way, the resonant frequency (usually in the centimeter range) is characteristic of selected atomic or molecular energy transitions, and therefore, the resonant circuit is not subject to ageing and has a very high Q. Unfortunately, the effective Q of these transitions is reduced because of the thermal motion of the gas particles (Doppler broadening), and because of the finite interaction time of particles and field as a result of gas collisions (pressure broadening) and of wall collisions. By operating with a low gas pressure so that the mean free path is larger than the wavelength, and by making the cell size larger than the wavelength, the collision broadening effects can be made small compared to the Doppler effect. As a result of Doppler broadening, ammonia molecules at 0°C have a Q of about 0.7×10^6. The Doppler effect is proportional to the square root of the gas temperature and therefore may be reduced by operating the cell at a lower temperature. Operation of the cell at liquid helium temperature, however, will reduce the Doppler width by only a factor of 4.4. A recently described ammonia absorption clock which uses Stark modulation (a strong electric field to slightly modify the resonant frequency of the ammonia molecule) has achieved a short time stability of 2×10^{-9}.

The effect of Doppler broadening can be reduced considerably by focusing the atoms or molecules into a beam, since it is the transverse velocity of the particles relative to the microwave field that results in the broadening. As an example of the effectiveness of the method, for a beam with an angular spread of 1.5 degrees, the Doppler width is reduced by a factor of about 38, which is equivalent — from the Doppler point of view — to a reduction of gas temperature to about 0.26°K. There are two important beam methods in use — the cesium atomic clock and the ammonia molecular beam oscillator.

The cesium atomic clock is based upon the principle that the energy transition in cesium 133, which corresponds to a frequency of 9,192.63197 Mc also corresponds to a change of magnetic moment of the cesium atom. In this way, one is able to let the cesium atom interact with a microwave field which induces energy transitions (if it is of the right frequency) and then test for these transitions by means of the beam deflections produced by an inhomogeneous magnetic field acting upon the corresponding induced magnetic dipole transitions. Figure 1 illustrates the principle of operation. The beam passes through the first inhomogeneous magnet (A), which deflects atoms with a given magnetic moment so that they pass through subsequent collimating slits and therefore removes all cesium atoms not of this magnetic moment. These selected cesium atoms then pass through microwave fields

Figure 1. Cesium atomic beam frequency standard.



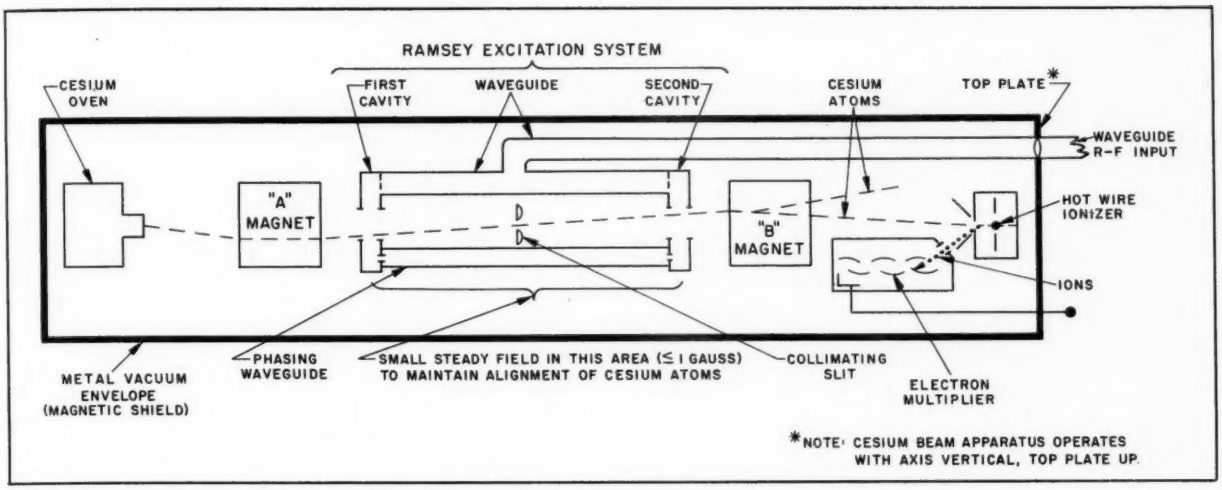


Figure 2. Cesium atomic beam frequency-standard apparatus.

which attempt to induce transitions. Only atoms which experience the desired transitions will have the correct magnetic dipole moment to be deflected by the second inhomogeneous magnetic field to fall on the hot wire ionizer (a tungsten filament with a work function higher than the ionization potential of cesium). The resulting cesium ions are accelerated and are collected by a secondary-emission electron multiplier whose electrical output is a measure of the number of cesium atoms striking the hot wire ionizer and therefore, a measure of the number of cesium atoms making the transition. This output signal, which is a measure of the agreement between the microwave frequency and the characteristic frequency of the transition, can, by means of a feedback loop, be used to make the microwave frequency almost equal to the transition frequency. The hot wire ionizer and electron multiplier is quite sensitive and can be used to detect a cesium beam of only 10^4 atoms per second. The Ramsey system of exciting the microwave cavities is quite ingenious. It permits one large cavity to be replaced by two smaller cavities, thus permitting a larger effective interaction distance between atoms and microwave field for cavities operated in the mode for maximum interaction. The basic limitation on the Q of the beam is now the interaction time between the cesium atoms and the microwave field. As a result of the Heisenberg uncertainty principle, the frequency corresponding to an interaction cannot be specified more accurately than about $1/\Delta T$, where ΔT is the interaction time between the particle and the field. This can also be seen by expanding a gated wave train of interval ΔT into its Fourier spectrum and noting that the half width of the major peak is approximately given by $1/\Delta T$. As an example of this basic limitation on the Q beam, an atom starting from rest and in free fall (under the influence of gravity only) through a cavity of effective length of 1 meter will pass through this cavity in about ½ second and for cesium with a frequency of 9,192+ megacycles, this corresponds to a Q of about 5×10^9. The frequency stability of the system can be increased above that indicated by the Q by using a detector and amplifier capable of detecting slight changes of beam output and by using a very constant beam source and microwave power source. Accuracy claimed for a cesium atomic beam frequency standard is about one part in 10^{11}, which corresponds to 1 second in 3,000 years.

The ammonia oscillator is an ingenious generator of constant frequency microwave power, which requires no vacuum tubes. The ammonia molecule has an electric dipole transition with a corresponding frequency (for the 3.3 inversion) of 23,870.13097 megacycles. Ammonia gas at room temperature has a good fraction of its molecules in excited states. Since the molecules in the upper and lower states have different electric dipole moments, it is possible to separate them by means of an inhomogeneous electric field and to introduce the excited molecules into a microwave cavity tuned to the frequency cor-

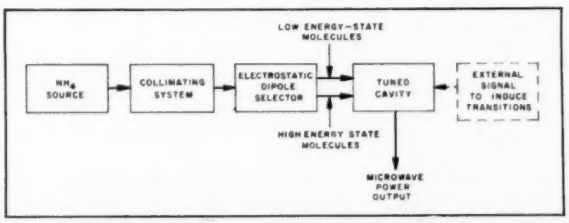


Figure 3. Ammonia Mollecular oscillator.

responding to a transition to the lower state. These transitions are made coherent, either by the cavity oscillations which build up, or by some external microwave power of the right frequency which induce transitions to the lower energy state. For a microwave power of 10^{-10} watts, an ammonia beam of 6×10^{12} excited molecules per second is needed. It can be seen that the microwave energy released in the cavity is supplied by the thermal energy of the ammonia molecules in the ammonia source. The principle of operation is illustrated in Figure 3. Since the Q of the beam is essentially determined by the interaction time of the ammonia beam and the tuned cavity, an ammonia beam in motion only through the influence of gravity and moving through a cavity 1 meter long will have a beam Q of about 10^{10}. This is an upper limit. The actual Q is about 3.4×10^6 for the Columbia University model. The deviation of the output frequency from the inversion frequency is related to the pulling effect of a slightly mistuned cavity. It can be shown that the ratio of the oscillator frequency deviation to the cavity frequency deviation is equal to the ratio of the cavity Q to the beam Q. The lowest temperature coefficient material available for cavity construction is a special super inversion with a temperature coefficient of about 10^{-7}/°C. Thus, for a cavity Q of 5,000 and a beam Q of 3.4×10^6, the frequency stability should be limited to about one part in 10^{10} for one degree temperature change. The stability of such an oscillator was reported to be about 1×10^{-10} over an hour.

An important feature of the ammonia beam oscillator is that it can be used as a MASER if the internal feedback is reduced until the input signal controls the induced coherent transitions to lower energy states. The MASER (Microwave Amplification by Stimulated Emission of Radiation) was first developed by C. H. Townes and co-workers of Columbia University in conjunction with their work on the ammonia oscillator or ammonia clock. The basic mechanism of the ammonia oscillator, as stated above is the interaction between radiation in a cavity and a beam of excited ammonia molecules to induce coherent de-excitation of the ammonia molecules and the consequent release of applicable microwave energy. If the cavity losses and the loading losses are low enough, the radiation released through induced de-excitation will be sufficient to supply these losses and to induce de-excitation of subsequent excited molecules without the need for external microwave energy. The unit will, therefore, operate as a microwave oscillator. Operation of the unit just below oscillation will permit the coherent transitions to be controlled by an external microwave signal and in this way microwave amplification is produced with the possibility of very low noise level.

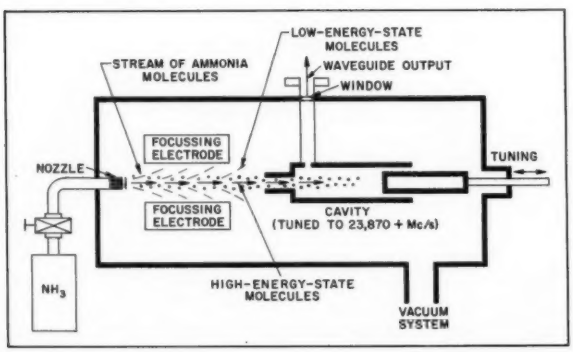


Figure 4.

A much more convenient solid state MASER has been proposed which uses transitions between split levels in paramagnetic crystals. MASER amplifiers have been reported using impurities (phosphorus) in silicon. The basic theory of the solid state MASER can be given in the following way. Consider a system with three (for example) unequally spaced energy levels, $E_3 > E_2 > E_1$. The population of the level E_3 is increased by the introduction of energy of frequency $\nu_{31} = (E_3 - E_1)/h$, where h is Planck's constant of 6.625×10^{-34} joule-seconds, until the population of level E_3 is larger than the population of level E_2. This is necessary because under normal conditions of thermal equilibrium, the population of level E_2 is slightly larger than E_3. Introduction of a small microwave signal of frequency $\nu_{32} = (E_3 - E_2)/h$ will, therefore, induce more coherent transitions from E_3 to E_2 than in the reverse direction because of the larger E_3 population, with a consequent net production of microwave energy of frequency ν_{32} and a resulting amplification of the original signal. The frequency and bandwidth of the solid state MASER can be controlled, and this fact represents a considerable improvement over the ammonia beam type of MASER. The source of the microwave energy of frequency ν_{32} is the microwave energy of higher frequency ν_{31}, and thus the solid state MASER operates as a "frequency transformer."

Applications of Plastics in Electronics

R. L. MONDANO
and A. I. SIMON

Research Division

PLASTICS is presently passing into another of its development stages. The electronics industry is becoming interested in the extent to which the mechanical and electrical properties of new plastics can be varied and controlled. For example, considerable time is now being spent on the study and the resulting properties of various "alloys" of thermosetting resins. To the engineer, the term "alloying" is not new. In actuality, the molecular structures of the thermosetting resins are complex, and by combining two or more different types, very complex and involved molecules result, the product of which is being referred to in the industry as a "plastic alloy." The following curves illustrate quite clearly the wide range of mechanical properties that can be obtained by "alloying" techniques. The epoxies, polyamids, and polysulfides are three of the best available resins which can be combined to give thermosetting alloys.

The alloy can be compounded to provide a great number of desired properties, but unfortunately, not all properties can be obtained from one magic alloy. As an example, to obtain resistance to high temperature, say, continuous operation at 400°F, the alloy would have to have a very tight molecular structure, which would not make it suitable for application where mechanical shock was involved. If the alloy were designed for mechanical shock, it would not be able to operate at high temperatures. The area under the stress strain diagram is an indication of the toughness of an engineering material. The graph in Figure 1 makes evident the very significant differences in toughness of the different resins cited. The resins referred to in Figure 1 are unreinforced, and alloys composed of these resins have a small range of ultimate strength properties. As an example, the ultimate strength in tension at standard atmospheric conditions varies from approximately 6,000 to 11,000 psi. However, combining the various reinforcements with these alloys can yield ultimate strengths in tension ranging from 15,000 to 55,000 psi. The most commonly used of these reinforcements has been fiberglass. However, reinforcing fabrics and fibers such as Nylon, Dacron, Orlon, and Dynel have proven to be superior in some phases, such as moisture absorption, adhesion of resin to fibers, and, in some applications, for mechanical resistance to loading and shock. Glass still appears the more desirable reinforcement for electrical applications and where high temperatures are involved.

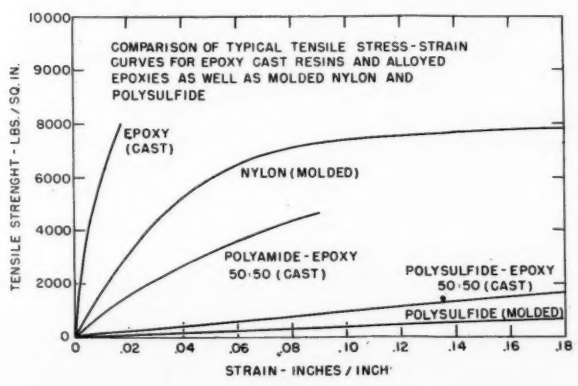


Figure 1

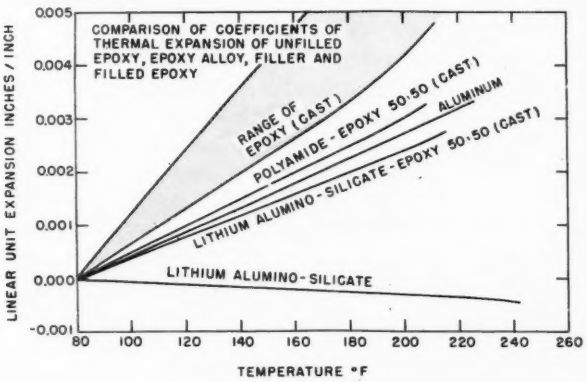


Figure 2

Of particular interest in the area of mechanical properties is the coefficient of thermal expansion. Critical applications, involving the need of uniform expansion of metal and plastic combinations for reliable operation, make it mandatory that the coefficients of thermal expansion of the plastic match to a close degree that of the metal. An example of this is the application of thermosetting resins to high speed rotors and stators, which operate at relatively high temperatures. Here, it is necessary to maintain a minimum gap between rotor and stator, which would require such close matching of the plastic and metal thermal expansion coefficients. The curves in Figure 2 show the results of various alloying techniques, as well as plastic and inorganic filler combinations. The inorganic filler and resin combinations make it possible to obtain certain mechanical properties, such as hardness and high

temperature performance, which straight alloying cannot. As an example of the ceramic filler and resin combinations, lithium alumino silicate is cited as a filler, whose curve of thermal expansion is shown in Figure 2. This composition is readily available in zero thermal expansion composition. The lowest expansivity of these compositions has been measured to be -6.5×10^{-6} inches per inch per °C.

Carrying the coefficient of thermal expansion studies one step further to include resins reinforced with glass fabric, some interesting results are obtained. A fixed pattern of behavior of coefficients of thermal expansion was ascertained to be directly related to the orientation of the glass cloth used. Some typical examples of this reference are shown in Figure 3. Curve 1 shows the results of subjecting

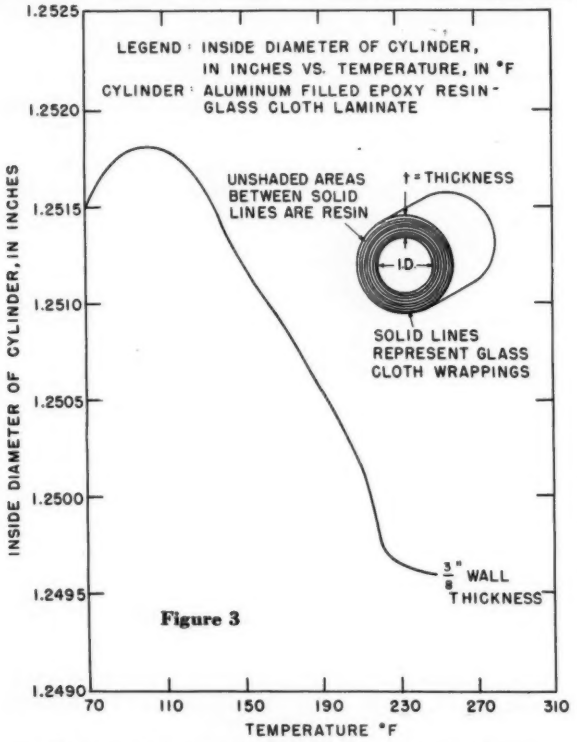


Figure 3

a cylinder of given dimensions to a rise in temperature from 70° to 250°F. Fundamentally, the coefficient of thermal expansion of glass is approximately 7×10^{-6} inches per inch per °F and that of the resin used in the test 60×10^{-6} inches per inch per °F. One can conclude from this that the resin would tend to expand much more than the glass, but also that the glass would, for the most part, act to restrict expansion of the resin. From 70° to 100°F we note an increase in I.D. of the cylinder tested. This is an illustration of the point brought out above. The resin begins to expand immediately, and due to the twist in the yarns and the crimp in the fabric, a certain per cent strain is necessary before the glass fibers can pick up the force exerted by expansion and restrict further expansion. On a rise in temperature from 100°F upward, there is a continual decrease in the I.D. of the cylinder tested. This is in further support of the theory discussed above.

Another example of the thermal expansion behavior of reinforced plastics is shown in Figure 4. The layers of glass fabric were carefully laminated so as to keep the warp and the fill in the same plane relative to each succeeding layer. When this laminate was cured, a hole was bored in the center and temperature expansion behavior measured. Figure 4 shows the results of the tests. The diameter of the hole was measured in the plane of the fill and the warp. The 90° curve, which is in the same direction as the fill or the warp, shows the uniform rate of expansion monitored by the glass filaments, which permit the resin to expand only at the rate at which the glass expands in the direction measured. At 45° to the warp and the fill, there is a vector quantity of resistance by the glass to the expanding resin, which is considerably less monitoring than that which existed in the fill and the warp direction. This is commonly referred to as motion on the bias. By staggering the orientation, uniformity of thermal expansion can be obtained in any direction in the plane of the laminate.

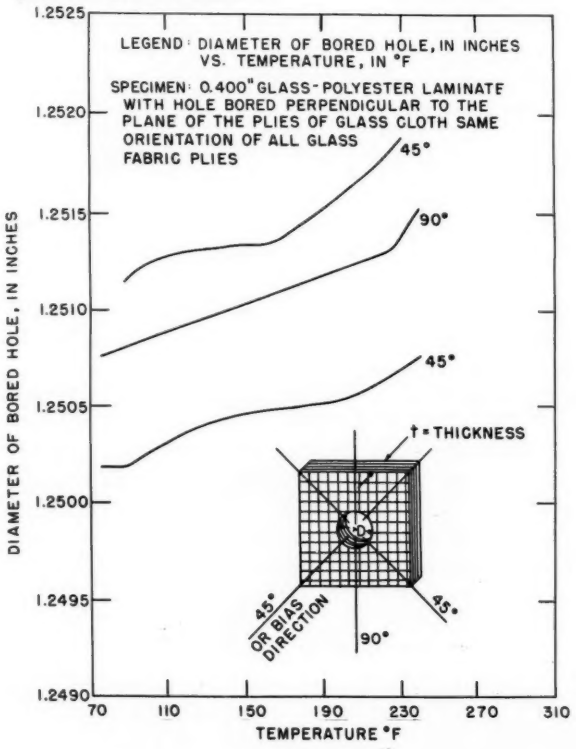


Figure 4

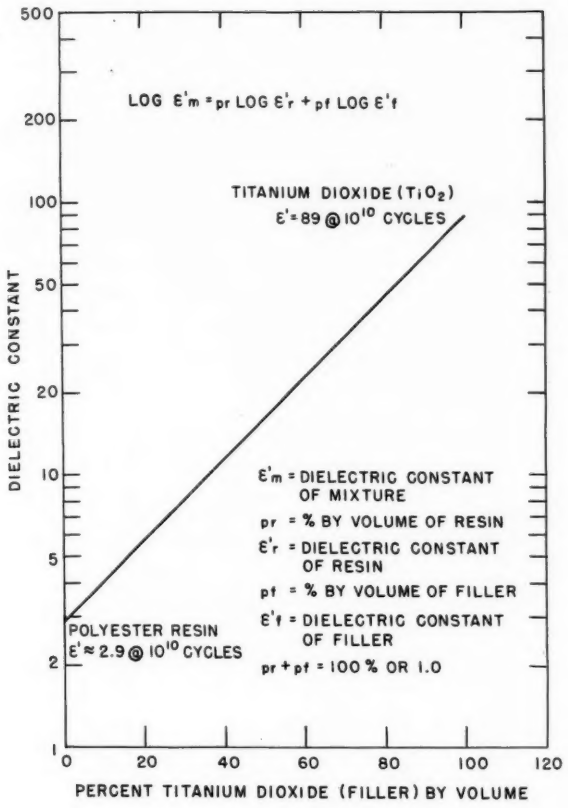
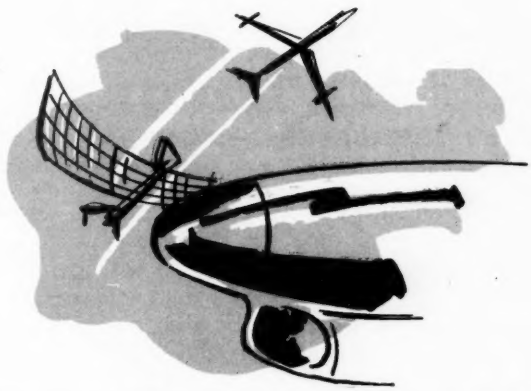

LOG ε'm = pr LOG ε'r + pf LOG ε'f
TITANIUM DIOXIDE (TiO_2)
ε' = 89 @ 10^{10} CYCLES
DIELECTRIC CONSTANT
ε'm = DIELECTRIC CONSTANT OF MIXTURE
pr = % BY VOLUME OF RESIN
ε'r = DIELECTRIC CONSTANT OF RESIN
pf = % BY VOLUME OF FILLER
ε'f = DIELECTRIC CONSTANT OF FILLER
pr + pf = 100 % OR 1.0
POLYESTER RESIN
ε' ≈ 2.9 @ 10^{10} CYCLES
PERCENT TITANIUM DIOXIDE (FILLER) BY VOLUME

Figure 5

A great deal of work was necessary to evaluate the mechanical properties before applications for electrical performance and properties could be considered. An example of this is the plastic radome. At first the dielectric constant of a sample of the proposed radome wall was measured, and the radome then designed in shape and thickness to provide the optimum compromise between the electrical properties and the system requirements. Concentrated efforts in the study of dielectric constants of plastics have yielded some interesting results as shown in Figure 5. Also included on the graph is the mathematical relationship between dielectric constant and resin-filler mix in obtaining a specified dielectric constant. Ceramic powders in combination with thermosetting resins have made it possible to obtain suitable dielectric constants of thermosetting resins from 2.8 to approximately 20, with loss tangent values as low as 0.010 at frequencies of 10^{10} cps.

The use of foam resins loaded with high dielectric materials such as ceramics, or with finely divided metal particles, has to date defied attempts to establish a relationship similar to that shown in Figure 5. Primarily, problems have been concerned with



the many variables encountered in the process. Considerable work is under way in this field. Some preliminary results are shown in Figure 6. Future work will involve careful control, the objective being the establishment of predictable and reproducible properties, despite the number of variables involved.

Efforts to obtain a low resistivity d.c. conductive thermosetting resin have yielded some encouraging results. While the volume resistivity of unfilled thermosetting resins is in the range of 10^{14} to 10^{18} ohm cm, to date, thermosetting conductive compounds have been made with resistivity values in the range of 0.2 to 0.5 ohm cm. This is encouraging for R.F. reflectors and, possibly, for R.F. waveguide components. Electroplating to these conductive surfaces has been proven possible, and when the surfaces are properly prepared, excellent adhesion through severe environmental conditions has been observed.

Reference is made to Vol. 1, No. 1 of ELECTRONIC PROGRESS, where liquid ammonia metallic sodium surface treatment of Teflon for bonding was discussed. Since this announcement, measurements of dielectric constant and loss tangent at 10^{10} cps have been made and no changes observed before and after such treatment.

FORMULATIONS

(Parts by Weight)

FOAMS

SAMPLE NUMBER	1	2	3	4	5	6	7	8	9
Silicone DC7002	100	100	100	100	100	100	100		
Barium Titanate	70	70	70	60					
Aluminum Powder MD7100	6	6	7	10					
Unicel N.D.			1	1					
Titanium Dioxide					40	67	40		
Epoxy Foam								100	100
Aluminum — Reynolds 40XD								8.45	
Aluminum Misc. Flake									9.1
Density	30.5	48.3	34.3	28.8	51.5	57.4	43.5	19.1	17.6
Dielectric Constant @ 10^{10} cps.	2.8	3.37	2.47	2.93	2.67	2.88	2.37 to 2.61	2.26	2.61

Figure 6

A Multiple-Filter Spectrum Analyzer

N. P. CEDRONE

Missile Systems Division

THE first spectrum analyzers in general use were of the "sweeping gate" or "panoramic" type, consisting effectively of a single bandpass filter which is swept over the frequency band of interest. The amplitude and frequency of each of the spectral components of the input signal is determined from the amplitude of the output of the filter and the frequency position of the filter at the time of the output. The information relative to the spectrum is indicated on some suitable display.

This method of analysis suffers from the disadvantage that the frequency resolution, which is basically proportional to the bandwidth of the filter, and the rate of analysis are intimately tied together. Each spectral component must lie within the bandwidth of the sampling filter for an interval of time at least equal to the time constant of the filter in order to assure the buildup of an adequate output signal.

The time constant τ of a simple filter, which is the time required for the output of the filter to build up to 1/e of its steady state value for a step input, is equal to $1/\pi B$, where B is the three-decibel bandwidth of the filter. Thus, the fastest practical rate of scan df/dt is equal to B/τ or πB^2 cps per second. Since the frequency resolution r is proportional to B, df/dt is equal to $\pi k^2 r^2$. The constant of proportionality k lies in the approximate range 2 to 5 depending on the steepness of the skirts of the filter.

The time T necessary to scan a frequency band W cps wide is equal to $W/(df/dt)$ or $W/\pi B^2$. The duration of a signal having a spectrum within the bandwidth W should be at least 2T in order to insure that the signal will be available for the interval of one complete scan. Since T for the usual "sweeping gate" analyzer is relatively large, this limits the effective use of the analyzer to the analysis of relatively long duration signals and steady state phenomena.

The ever increasing need for transient analysis has resulted in the development of the "fixed filter array" type analyzer. This type consists of an array of filters covering the frequency band of interest with adjacent filters having cross-overs somewhere in the vicinity of the three-decibel points. The signal is fed simultaneously to all the filters and the outputs are sequentially scanned by some appropriate method and presented in some suitable display which indicates both amplitude and frequency of the instantaneous spectral components.

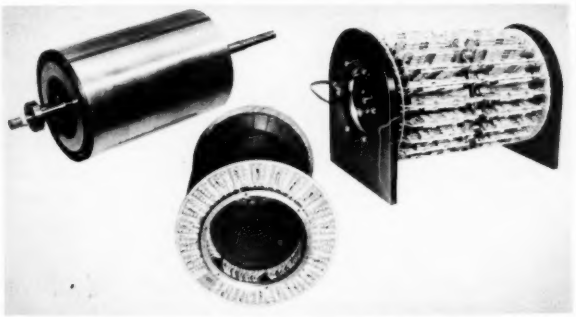


Figure 1. Physical characteristics of the filter and commutator assembly.

In this type of analyzer, the scanning time is not tied down to the filter buildup time. The bandwidths of the filters are set by the frequency resolution desired as well as by the minimum time length of the signals. The time constant of the filters, as a rule-of-thumb, must be at most equal to the duration of the phenomenon to be analyzed. The bandwidth is free to be set for the desired resolution within the limits of the above restriction.

The scanning rate has a lower limit determined by the duration of the shortest signal. Since, presumably, these signals may occur at unpredictable times, it is necessary to have scan rates approximately equal to the reciprocal of the minimum expected duration in order not to miss any of the short duration signals. Scanning at faster than the minimum rates results in more detailed information of signal characteristics as modified by the transient response of the filters themselves.

The Raytheon Spectrum Analyzer was one of the first of the filter array type to be developed and used. It resulted as a by-product of a radar system development within the present Missile Systems Division. It consists of an array of four hundred and twenty magnetostriction rod filters of nominally equal bandwidths. The center frequencies of adjacent filters are separated by a frequency interval slightly less than the bandwidths of the individual filters. The filters are fed simultaneously with the input signal. The output of each filter is sequentially fed to one stator plate of four hundred and twenty lining the inside of a drum. Inside this drum is a rotor with a sampling strip, running the length of the rotor, which by means of capacity coupling samples the outputs of successive filters.

The sampled output, after detection, is fed to an oscilloscope in an "A" type presentation. The

height of the pip represents the amplitude of the spectral component and the distance along the trace represents frequency, the scope trace being synchronized with the output scan. Other types of display can be and have been used.

The stator plates are divided into two sets of equally spaced individual plates extending half way along the length of the drum from each end. The two sets are displaced relative to one another, such that the centers of one set of plates are in line with the centers of the space between adjacent plates of the opposite set. The outputs of the filters tied to one set are out-of-phase with the outputs of the filters tied to the other set.

The sampling strip when centered over one stator plate is just wide enough to cover half the adjacent plates of the opposite set. Thus, the sampling strip samples the full output of the centered stator plate and half the out-of-phase outputs of the opposite plates. This "out-of-phase" summation, through a skirt cancellation effect, effectively increases the slopes of the basic filters from six decibels per octave to eighteen decibels per octave resulting in significantly increased frequency discrimination.

The sampling speed of the analyzer is determined approximately by the reciprocal of the time constant of the individual filter bandwidths. Thus, for the analyzers fabricated at Raytheon having nominal filter bandwidths of 10, 30, and 90 cps, the sampling speeds are aproximately 1800, 6000, and 15,000 scans per minute, respectively.

The quality of performance of the analyzer may be judged in terms of its resolution and the constancy of the output amplitude response to an input signal of fixed amplitude as it is varied in frequency across the frequency band covered by the analyzer. The resolution for out-of-phase summation has been measured to be approximately two and one-half times the bandwidth of the filters. In this case, resolution is defined as the frequency separation of signals of the same amplitude, which results in an indication of two peaks with a six decibel valley between them. The presence of two signals almost superimposed can be determined by a beating effect. In the last year, the flatness of response obtainable has improved considerably. Analyzers are fabricated now with an over-all output amplitude response variation within plus and minus three decibels over the entire frequency band.

Some idea of the physical characteristics of the filter and commutator assembly may be obtained from Figure 1.

The Raytheon spectrum analyzer employs electromechanical filters which are thin rods of ferromagnetic material excited in the longitudinal mode of vibration through the magnetostriction effect. Figure 2 is an exploded view of the components of the filters showing the rod element, the node washers used as support and for suppression of undesired vibrational modes, the drive and pickoff coils and the completed filter tube assembly. Figure 3 is a complete 20-filter package showing the clip-mounting technique and the ferrite bias magnets.

Although other promising materials have been investigated for use as the active filter element, Ni-Span C has been the most successful in Raytheon's experience and is the only material used in the analyzers. The practical range of Q is from 4,000 to 10,000 although Q's somewhat outside this range are also available. Practical filters have been built having bandwidths of from 2 cps to 160 cps operating at center frequencies of from 20 kcps to about 350 kcps. The thermal coefficient of center frequency averaged over the interval 0°C to 50°C ranges from about 2 to 12 parts per million per degree Centigrade, which compares very favorably with crystal filters.

During the first years of experience, very little was known or understood about the relation between the characteristics and the stability of the filter and the composition, plastic deformation, heat treatment and magnetic history of the basic rod material, or about the effects due to the material and packaging of the other components. However, within the last year or so, under the impetus of an Air Force R and D contract, a cooperative effort on the part of Missile Systems and Research Divisions has contributed much to an understanding of filter behavior.

It is possible now not only to make much better filters but also to predict to within a practical accuracy the characteristics of a filter from a knowledge of the basic properties and histories of the heat and mechanical treatments of the rod material. This can be done not only for Ni-Span C but for other materials as well. Further basic work is now being done in an attempt to explain the magneto-elastic mechanisms involved in the determination of the filter characteristics and the temperature dependences of these characteristics. Recent theoretical advances in solid state physics involving internal friction, crystal and shape anisotropy of special ferromagnetic materials and precipitation-hardening alloys have suggested experiments which are intended to increase the range of usable Q, improve reproducibility for large batches of filters and particularly to improve the linearity of electrical characteristics.

In the Missile Systems Division the analyzer has been and continues to be an extremely useful instrument. Its use in the analysis of flight data has been in part responsible for the improvement of

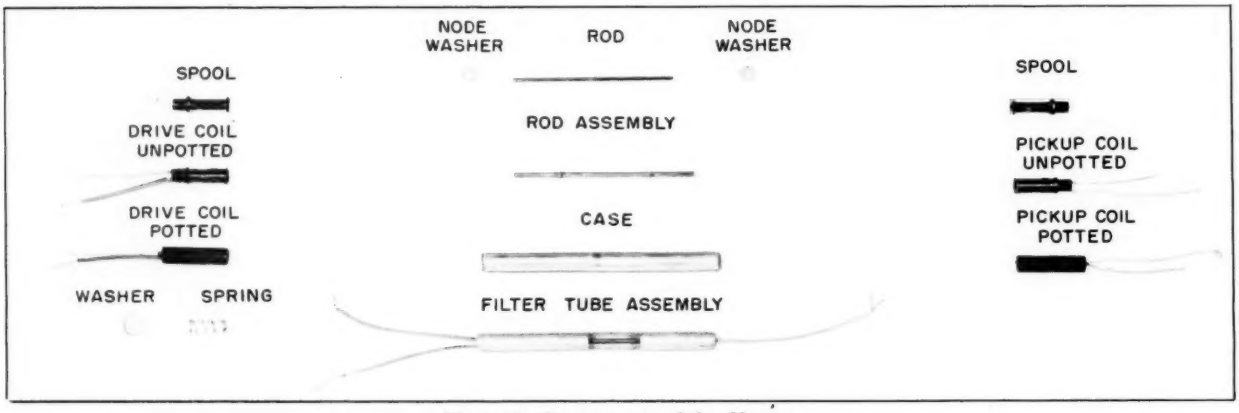


Figure 2. Components of the filters.

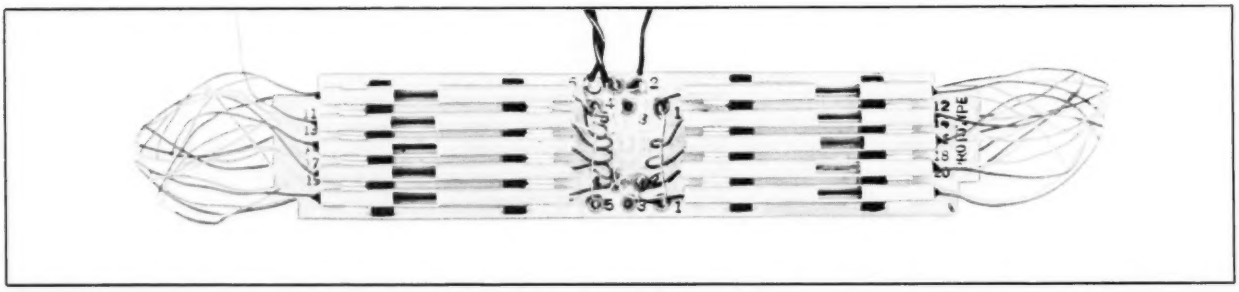


Figure 3. Complete 20-filter package.

systems under development. Its many other applications include noise analysis, the effects of shock and vibration on mechanical and electrical systems, and speech analysis and synthesis.

The future of both the filters and the analyzer looks very promising. The filters are being investigated for use in radar systems under development at Raytheon and elsewhere, applications requiring large numbers of filters for which the relative ease of fabrication is a real advantage. Their small size, light weight, relative insensitivity to shock and vibration, low power requirement, and impedance characteristics matching those of transistors makes them ideally suited to airborne systems application. The present analyzer is somewhat inflexible both in the number of mechanical filters and in the rate of scan which is limited at present to 15,000 rpm. The present development of a smaller capacity commutated one hundred filter unit and improved electronic sampling methods should considerably increase flexibility and broaden the interest in the analyzer, not only as a versatile laboratory instrument, but also as an integral part of data processing and detection systems.

Inventions

Congratulations to the following persons for their valuable contributions to Raytheon's portfolio of inventions:

Name	*Field of Invention*
Bassett, M.	Spacer
Blattel, A.	Cathode
Blattel, A. & Duchoviner, M.	Tube Mount
Brown, W. C.	Platinotron Duplexer
Clampitt, L. & Zawada, F.	Magnetron End Space Design
Copson, D. A.	Food Freeze — Drying Method
Decareau, R. V.	Food Drying Method
Dench, E. C.	Combined Oscillator and Amplifier
Domenichini, C. P. & From, W. H.	Microwave Switch
Ellis, R. C., Jr. & Leverton, W. F.	Silicon Decomposition
Gaziano, J. S.	Fin
Harmer, J. D.	Transistor Amplfier
MacDowell, K. & Rapuano, R. A.	Superregenerative Amplifier
McLeod, W. W., Jr.	Antenna System
Mogey, L.	Yellow Band
Murphy, W. M., Jr.	Oscillator
O'Hara, F. & Scharfman, H.	Phase Shifter
Pritchard, W. L.	Antenna
Schall, L. H.	Oven Door
Scharfman, H.	Phase Changer
Schloemann, E.	Ferrite Loaded Line
Sheehan, W.	Audio System
Smith, C. G.	Crystal Growing
Smith, W. A., Jr.	Waveguide Coupling
Spanos, J.	Semiconductor Connector
Ticehurst, L. E.	Power Transfer Device
Williams, J. R.	Transistor Pellets
Wilson, R. D.	Ceramic Tube
Woo, W. G.	Heater Voltage and Current Control
Zimmer, J. T.	COHO Compensation

Publications & Papers

"Physical Meaning of Section Modulus"

M. DANILOFF
Engineering (London)

September 14, 1956

Abstract: The concept of the "section modulus" used in the theory of pure bending of prismatic bars (the "second problem of Saint Venant") possesses simple physical meanings which are seldom brought out with all possible clearness in the standard texts on the subject.

The concept of "unit-moment stress" and "unit-stress-moment" are introduced and it is shown that the "section modulus" is precisely the "unit-stress-moment".

"Transformer Miniaturization Using Fluorochemical Liquids and Conduction Techniques"

L. F. KILHAM, JR., and R. R. URSCH
M. I. T. Industrial Liaison Symposium

November 13-14, 1956

Abstract: Reduction of size and weight in electronic type transformers to keep pace with miniaturization in other phases of electronic component designing has led directly to higher temperature operation. Temperatures in the region of 185°C require inorganic materials throughout including, where used, the dielectric coolant. Design details and materials performance in "miniaturized" electronic type transformers are discussed in this paper. Specific Class A transformers are redesigned using these new techniques, thus giving size comparison.

"The Argon Bombardment and Oxidation of Germanium Surfaces"

S. P. WOLSKY
Chicago Meeting of American Physical Society

November 1956

Abstract: A sensitive quartz microbalance set up in a vacuum system capable of attaining pressures of 5×10^{-10} mm. has been used to study the argon bombardment technique for the preparation of clean germanium surfaces. The efficiency of the bombardment process expressed as the number of germanium atoms removed per argon ion striking the surfaces appears to be unity under the conditions of the experiment. The quantity of argon remaining in the lattice after bombardment has been found to be as large as 10^{18} atoms/cc. The room temperature oxidation of bombarded surfaces at 3 mm. oxygen pressure has yielded values in agreement with those of other workers.

"Vacuum Tube Vibration Studies" "Interpreting the Results"

R. D. WILSON
24th Shock & Vibration Symposium

November 11-13, 1956

Abstract: All too often, the results of vibration studies are misinterpreted because of insufficient information as to exactly how the data was obtained. This paper discusses the more common techniques of measurement, the equipments and operating frequencies used and the advantages and disadvantages of each method.

In addition, some typical test data are given and the results analyzed in terms of the various elements of the Tube Under Test.

"Production Design of Interdigital Line Backward Wave Oscillators"

R. C. HERGENROTHER, R. HARPER, E. SCHEFFLER, and R. McC. UNGER
Professional Group on Electron Devices Meeting

Washington, D. C., October 24, 1956

Abstract: The paper gives a brief discussion of the type "O" interdigital line, backward wave oscillator theory. The new tube design problems which are encountered in this type of backward wave oscillator and some practical solutions of these problems which have made it possible to fabricate these tubes with modern production methods are described.

A description is given of the laminated and interdigital line, of the line termination and output transition. A new type of ceramic brazed unitized electron gun designed for these tubes is described.

A description of the structure and electrical characteristics of a production S band tube having approximately an octave of voltage tuning is given as an example of the above work.

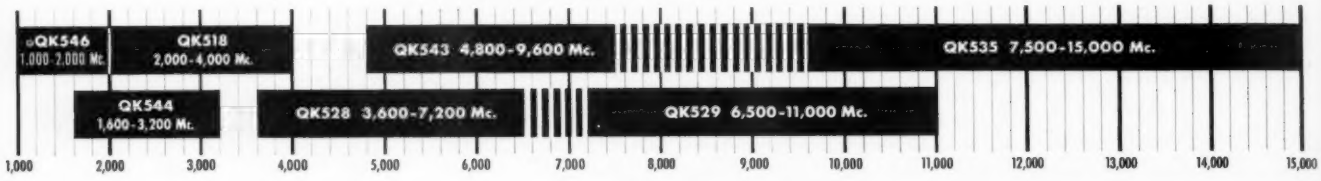
"Direct Cooling of Electronic Equipment with Heavy Inert Vapors"

J. F. AHEARN
M. I. T. Industrial Symposium

November 13-14, 1956

Abstract: A new method of cooling electronic equipment using high density inert dielectric vapors as the cooling medium has been developed at Raytheon and is being applied to the cooling of equipment designed to operate under severe environmental conditions in high speed aircraft. The method requires a minimum of added weight in the form of cooling medium and auxiliary equipment and provides a high factor of reliability due to the relatively low operating temperatures of components made possible by the new technique. Theory underlying the method is discussed and description is given of a practical power supply incorporating the heavy vapor cooling system.

VOLTAGE TUNABLE



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Frequency: 2,000-4,000 Mc.

Rapid electronic tuning by varying delay line voltage from 150-1,500 Volts.

Power output: 0.1 to 1 watt.

Complete with compact permanent magnet.

Approximate maximum dimensions: 10" long, 4⅜" high, 4⅞" wide.

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